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ROCK ANALYSES IN THE CAROLINA SLATE BELT AND THE CHARLOTTE BELT OF NEWBERRY COUNTY, SOUTH CAROLINA

by

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ABSTRACT

In the course of a study of the general geology of Newberry County ten samples of representative rock types from the Slate Belt and the Charlotte Belt were analysed chemically. These analyses in conjunction with field and petrographic modal analyses permit a first estimate of the average bulk compositions of each belt, in addition to providing useful data on the origin of the individual rocks.

The analyses of the Slate Belt rocks suggest that they originated predominantly from mixtures of siliceous land waste and mafic to felsic pyroclastic material. The Charlotte Belt rocks were originally submarine basalts and graywackes, later intruded and migmatized by granitic to granodioritic rocks.

In general, the average original bulk composition of the Slate Belt was andesitic, whereas, the average pre-metamorphic composition of the Charlotte Belt was considerably more mafic. In view of these chemical discordances, it is considered unlikely that the rocks of the two belts could be the metamorphic correlatives of one another.

INTRODUCTION

The general geological relationship between the rocks of the Caro-

lina Slate Belt and the adjacent Charlotte Belt (King, 1955) is one of the least understood aspects of Piedmont geology. Although a number of theories have been proposed to explain the distinctive character and interelations of the two belts, these interpretations generally lack sufficient detailed information to be completely acceptable. No attempt will be made in this paper to review all of the previously suggested theories nor to formulate additional alternatives. Its purpose is mainly to present new information on the bulk chemistry of the rocks from both belts and to attempt a first estimate of the average pre-orogenic composition of each. However, this first estimate of the average compositions of both belts does permit a critical evaluation of the widely circulated but generally unsubstantiated theory that the rocks of the two belts are essentially the metamorphic correlatives of one another.

The samples were collected during the course of an investigation of the geology of Newberry County, which lies across the two belts in question (Figure 1). Ten samples of the common rock types of both belts were collected and subjected to standard rock analyses in addition to the usual petrographic modal analyses. Since so little attention has previously been paid to rock chemistry in the southeastern Piedmont, the writer believes it appropriate to report and comment upon these analyses separately from the forthcoming report on the general geology of Newberry County.

ACKNOWLEDGEMENTS

The support of the Division of Geology, South Carolina State Development Board with whom the writer has been employed as a project geologist is gratefully acknowledged. The major portion of the funds for the rock analyses reported herein were provided by a grant from the University of South Carolina Committee on Faculty Research.

The chemical analyses were performed by Technical Service Laboratories, 355 King Street, Toronto, Canada, and the analysist was John E. Burgener.

Henry S. Johnson, Jr. of the Division of Geology, South Carolina State Development Board contributed numerous helpful suggestions and reviewed the final manuscript.

GENERAL GEOLOGY

The Carolina Slate Belt

The extreme southeastern portion of Newberry County, on the north shore of Lake Murray, is underlain by the western edge of the Slate Belt (Plate I). In this area the belt trends approximately N 70 E and consists in general of a sequence of phyllitic to schistose rocks which may be as much as 25,000 feet thick. The rocks assigned to the Slate Belt are within the greenschist regional metamorphic facies and are considered to be derivatives of volcanic flows and tuffs, intimately admixed and interbedded with land waste.

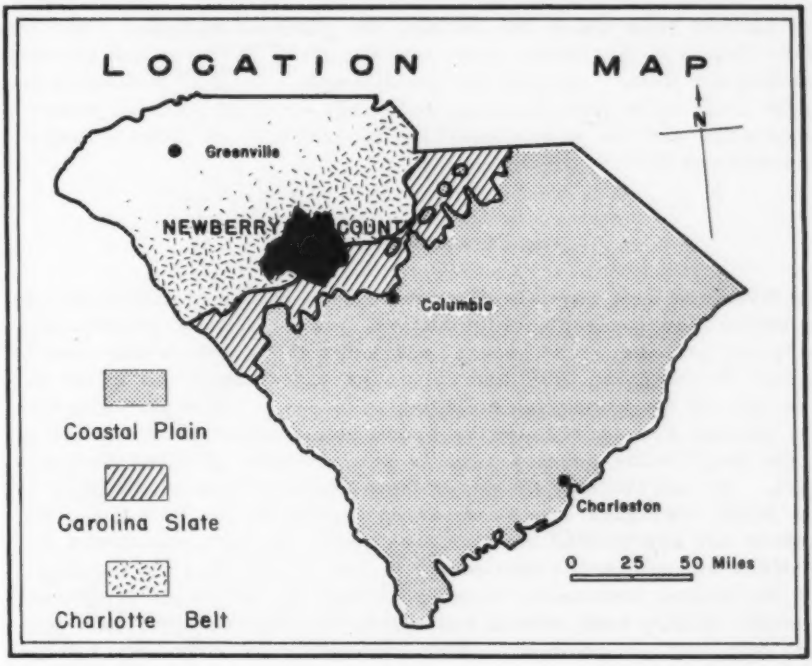


Figure 1. General location map.

Phyllitic rocks predominate in the southeastern part of the county. A number of distinct lithologic types are included in this category but poor exposures prevent their separation into mappable units. The most abundant of the phyllitic types is a quartz-"sericite" phyllite considered by Heron and Johnson (1958) to represent the felsic phase of the Slate Group. Less abundant types include quartz-chlorite phyllite and weakly foliated epidote rich rocks generally interbedded with the more abundant qyartz-"sericite" type. Heron and Johnson (1958) considered these two rock types as typical of the mafic phase of the Slate Group in this area. It is estimated on the basis of field mapping in Newberry County and in the Irmo Quadrangle that these "greenschists" constitute about twenty five per cent of total exposed rock.

The phyllitic rocks grade to the northwest into moderate coarse grained schists which in thin section appear to be the products of extreme mechanical deformation and metasomatic activity. These rocks form a narrow zone which lies between the greenschist facies rocks of the Slate Belt and the higher rank amphibolites, gneisses and granites of the Charlotte Belt. As with the phyllite unit a number of distinct interbedded rock types are present, including: chlorite schists, muscovite-quartzites and the anomalous kyanite quartzite at Little Mountain (Espenshade and Potter, 1960).

The Charlotte Belt

The Charlotte Belt consists of amphibolites, quartz biotite gneisses, quartz microcline gneisses, migmatities, granodiorites, granites and late orogenic gabbros. The general character of the belt in this area is mesozonal (Buddington, 1959) and the rocks surrounding the felsic intrusives are in the almandine amphibolite facies. The partially discordant plutons are surrounded by broad zones several miles wide in which the amphibolite country rock is substantially enriched in felsic material. At considerable distances from the intrusives moderately abundant felsic stringers can be observed parallel to the foliation. As the plutons are approached the stringers cross cut the foliation and also constitute a much larger percentage of the total rock. At the margins of the plutons themselves only small isolated blocks and fragments of the mafic country rock remain and within the plutons disoriented biotite rich zenoliths are common. This widespread assimilation of relatively high rank mafic country rock is one of the salient features of the Charlotte Belt throughout South Carolina.

Four distinct Charlotte Belt units can be recognized and mapped with reasonable accuracy within Newberry County. The first of these is informally termed the Charlotte Belt Gneiss. It includes amphibo-

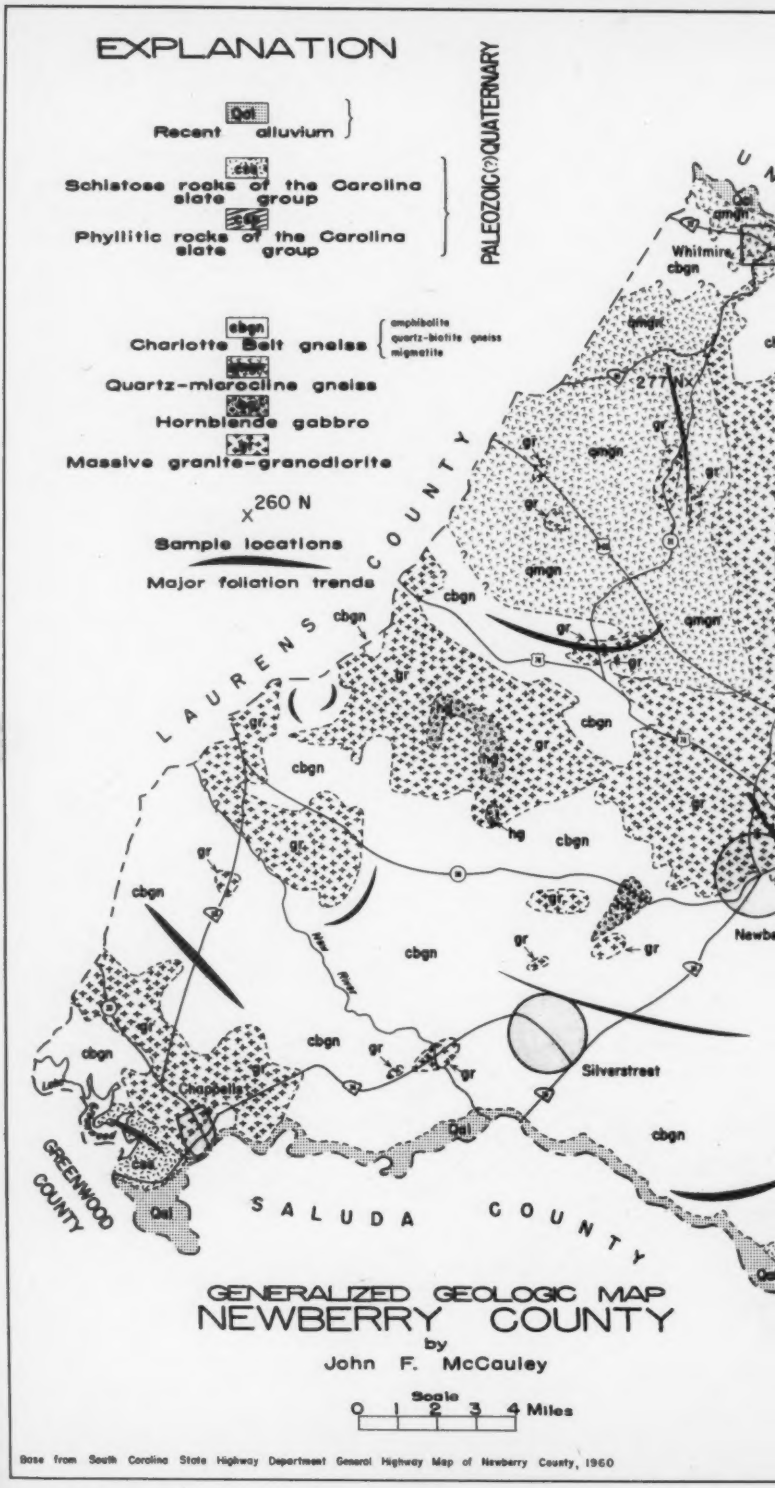
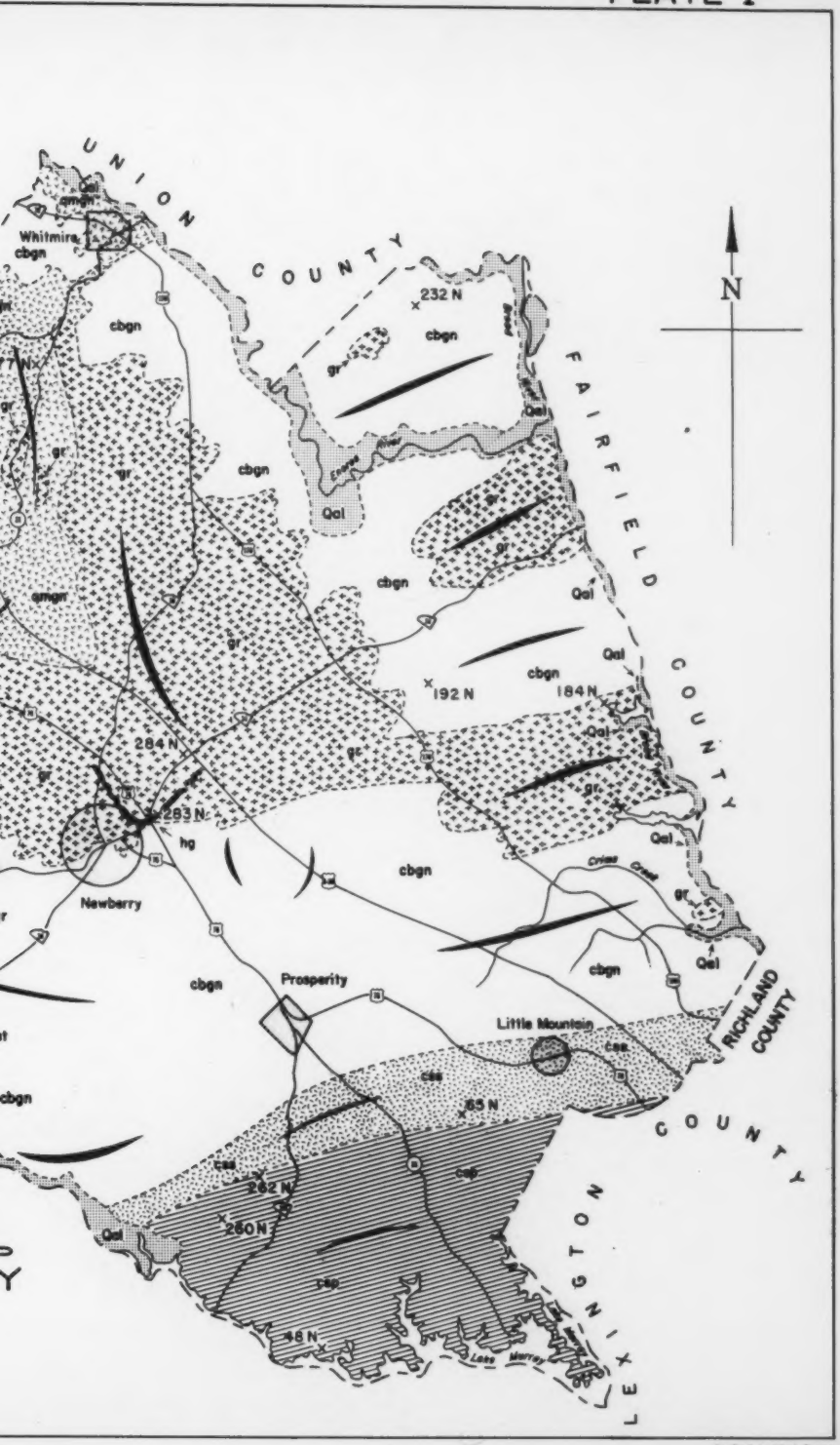

EXPLANATION
PALEOZOIC(?) QUATERNARY
Qal
Recent alluvium
cbg
Schistose rocks of the Carolina slate group
Phyllitic rocks of the Carolina slate group
cbgn
Charlotte Belt gneiss
amphibolite
quartz-biotite gneiss
migmatite
Quartz-microcline gneiss
Hornblende gabbro
gr
Massive granite-granodiorite
X 260 N
Sample locations
Major foliation trends
LAURENS COUNTY
GREENWOOD COUNTY
SALUDA COUNTY
Whitmire
Chappells
Silverstreet
Newbe
GENERALIZED GEOLOGIC MAP
NEWBERRY COUNTY
by
John F. McCauley
Scale
0 1 2 3 4 Miles
Base from South Carolina State Highway Department General Highway Map of Newberry County, 1960

PLATE I



Drafted by M. J. Green

lites interbedded with quartz biotite gneisses, along with abundant migmatite at the margins of the acid plutons. The second rock type is the massive to weakly foliated granite to granodiorite of the plutons. The third is a quartz-microcline gneiss which outcrops over an extensive area in the northwestern portion of the county. It exhibits pronounced foliation along which microcline porphroblasts up to an inch in length are developed. Retrogressively metamorphosed hornblende gabbros are the fourth mappable type. These occupy small plugs and arcuate dikes and are considered to be late orogenic (McCauley, 1961).

ROCK ANALYSES

Carolina Slate Belt Samples

Sample 1 (48-N) is a weakly foliated "greenschist" interbedded with lighter colored phyllites. Fresh exposures are rare because of its poor resistance to weathering and its overall abundance is not known, although it is apparently quite common in the Newberry County area as well as in other portions of the Slate Belt in South Carolina. In thin section, it is a granular mosaic of fine-grained quartz and lath-like, cloudy, yellow, iron-rich epidote (Table 1). The matrix consists of shreads and elongated flakes of white mica and two varieties of chloritic green mica. The white mica resembles sericite in physical appearance but contains, according to the chemical analyses (Table 2), only a negligible amount of potassium. Minor accessory minerals are magnetite and sphene.

The exceedingly low alkali content and the moderate silica percentage of this rock preludes its metamorphic derivation from a member of the basalt clan (Poldervaart, 1955, p. 134-135). On the other hand, the high lime and magnesia content along with the low alumina percentage strongly suggest that the rock is not a derivate of a shale or graywacke type sediment. The anomalous composition can better be explained by the mixing of terrigenous waste with basic tuffaceous material at the time of deposition. Upon metamorphism this rock became a siliceous epidote-rich greenschist similar in appearance to low rank metabasalt but distinct in chemical composition.

Sample 2 (260-N) is a dark green, well foliated phyllite also interbedded with lighter colored phyllites. It exhibits a well developed rock cleavage at an angle of sixty degrees to the bedding. Mineralogically it consists of highly angular quartz fragments elongated parallel to the

Table 1. Modes in Volume Per Cent

	1-48-N	2-260-N	3-262-N	4-65-N	5-232-N	6-192-N	8-184-N	9-284-N	10-283-N
Quartz	33	39.0	21.1	68	-	31	21.0	28.6	-
Plagioclase	-	-	-	-	33	34	44.1	36.4	36.3
K feldspar	-	-	-	-	-	15	25.9	26.4	-
Muscovite	9x	-	60.3+	31	-	3	-	1.4	-
Biotite	-	-	-	-	-	8	5.7	5.4	2.7
Chlorite	13*	59.9*	-	-	-	1	-	-	25.1
Epidote	44	-	0.7	-	-	trace	0.1	0.6	-
Hornblende	-	-	-	-	47	4	1.6	-	35.2#
Diopside	-	-	-	-	18	3	-	1.2	0.6
Opaques	1	1.1	17.9	-	-	1	.4	-	0.1
Apatite	-	-	-	-	-	trace	.2	-	-
Sphene	-	-	-	1	2	trace	1.1	-	-
Total	100	100.0	100.0	100	100	100	100.1	100.0	100.0
Specific Gravity (computed)	2.99	2.82	3.19	2.73	3.04	-	-	-	-
Composition of Plagioclase	-	-	-	-	An 30	An 20	An 10-15	An 12	An 50
Number of counts	500	1000	1500	920	1000	500	1000	500	1000

* Chlorite includes penninite and sericite
\+ Muscovite is intermediate in composition with paragonite
x Muscovite contains only a negligible amount of potassium (hydromica)
\# Hornblende includes themolite and actinolite

Table 2. Chemical Analyses

Table 2. Chemical Analyses

	1-48-N	2-260-N	3-262-N	4-65 N-1	5-232-N	6-192-N	7-277-N	8-184-N	9-284-N	10-283-N
SiO_2	59.68	49.50	45.92	68.18	49.10	64.88	64.86	66.36	70.50	49.10
FeO	4.03	14.51	1.03	.51	7.20	2.54	2.47	2,83	1.31	6.90
Fe_2O_3	6.38	7.87	17.64	5.87	4.97	1.85	5.56	3.27	2.16	2.58
Al_2O_3	10.91	16.24	23.38	14.83	11.00	12.84	13.86	12.30	12.47	16.94
CaO	9.25	1.04	1.24	1.52	15.35	4.45	4.14	3.68	3.00	10.15
MgO	3.66	5.00	0.31	0.61	7.54	6.62	1.31	0.94	0.75	6.69
MnO	0.12	0.26	0.01	0.02	0.14	0.08	0.05	0.09	0.04	0.10
Na_2O	0.13	0.47	3.13	0.57	2.38	3.92	3.13	4.26	3.73	2.26
K_2O	0.35	0.89	3.25	4.60	0.64	2.90	5.31	4.46	4.32	0.84
H_2O	2.66	2.50	0.86	0.92	0.10	0.18	nil	0.52	nil	1.92
CO_2	0.07	0.09	0.04	0.06	0.11	0.07	0.22	0.07	0.03	0.15
TiO_2	1.15	1.77	2.15	0.98	1.02	0.67	0.75	0.75	0.32	0.50
	98.39	100.14	98.96	98.67	99.55	101.00	101.66	99.53	98.63	98.13

bedding and interlayed with bands rich in white and green mica. X-ray analysis reveals the presence of sericite and penninite (Table 1). Extensive recrystallization of the chlorite has occurred on the cleavage surfaces along with shearing movements causing microscopic chevron folding of the original bedding.

Chemical analysis also shows this rock to be poor in alkalies despite the presence of sericite type mica. However, it is significantly lower in silica and lime and higher in total iron than the preceding sample. Except for the low alkali and high iron content it approaches the average oceanic olivine basalt in composition (Poldervaart, 1955, p. 134-135). This rock may also be of mixed origin but with a lower content of siliceous land waste. The low alkali content of both samples is unusual. It is inferred that the ferromagnesian pyroclastic material and the siliceous land waste that constitute these rocks were both originally low in alkali bearing minerals.

Sample 3 (262-N) is a light gray phyllite which megascopically resembles the quartz-"sericite" phyllite extensively developed over the southeastern portion of the county as well as in other recently described portions of the Slate Belt of South Carolina (Heron and Johnson, 1958; Ridgeway, 1960). In thin section it consists of irregular layers of angular quartz alternating with a felty mosaic of white mica. Generally flattened plates of hematite and minor ilmenite form indistinct layers

Figure 2. Thin section view of the white mica phyllite (262-N). Black is specular hematite, white is quartz, the line area is mica. Plain light, x50.

parallel to foliation. Epidote in the form of scattered subhedral crystals is a minor accessory (Figure 2).

Chemical analysis indicates a surprisingly low silica content which approximates that of the average ultrabasic rock (Poldervaart, 1955, p. 134). It differs, however, from the usual ultrabasic in its high ferric iron content along with substantially greater than normal percentage of alumina and alkalies. Petrographic and modal analysis indicates that the alkali-bearing mineral is the white mica which contains almost equal amounts of soda and potash. X-ray analysis establishes that neither sericite (muscovite) nor paragonite is present but rather a mineral with "d" spacings and lattice dimensions intermediate between the two. The overall abundance in the Slate Belt of this type mica is not yet known. Since it is optically indistinguishable from sericite it is possible that much of the white mica in the Slate Belt rocks previously identified as sericite may prove to be this intermediate soda-rich type.

The high percentage of specular iron oxide in this sample accounts, in great part, for its low silica content. The hematite shows no replacement relationship to the mica or quartz and is considered of primary sedimentary origin (Figure 2). Specular schists or "itarbirite" are widespread in the South Carolina Piedmont (Lieber, 1856). Recently O'Rourke (1961) has suggested that these occurrences represent a type of iron formation which is transitional between the Precambrian Lake Superior type and the Paleozoic Clinton type. The writer suggests that the hematitic schist under discussion formed in a restricted basin in which the admixed soda-rich tuffaceous material was deposited subaerially or by normal erosion and sedimentation from a nearby volcanic land mass.

Sample 4 (65-N-1) is a white to pale gray schist composed almost completely of quartz and white mica. It is believed to be representative of the lighter colored portions of the schist zone that separates the low rank phyllites of the Slate sequences from the higher rank metamorphics of the Charlotte Belt. Rocks of this type are interbedded with chlorite schists and kyanite and muscovite quartzites, for which no chemical analyses are yet available.

In thin section, the rock is essentially a granular mosaic of quartz with irregular layers and clots of muscovite distributed parallel to the foliation. Considerable crumpling of the mica occurs along a secondary fracutre system. Also present is a minor amount of sphene in the form of small irregular grains.

Chemically the rock is distinct from the phyllite type rocks previously discussed. It is higher in silica, greatly enriched in potash and

poorer in total iron. Whether the analyses of this specimen approximates the original bulk composition or whether it represents a metasomatic or possibly retrogressive product is questionable. The schist zone from which this specimen was taken is characterized by widespread silica transfer as evidenced by the presence of abundant quartz veins. Espenshade and Potter, 1960, considered the kyanite quartzite occurrences at Little Mountain to be of hydrothermal replacement origin. Recent work by the writer, however, suggests a metamorphic origin similar to that postulated by Hurst, (1959) for the Graves Mountain, Georgia occurrences. It is probably that during metamorphism considerable amounts of silica and potash were removed from the volcanic units now represented by the aluminous quartzites and redistributed into the surrounding schists, effectually enriching them in these components.

Charlotte Belt Samples

Sample 5 (232-N) is from a 6 to 8 foot thick hornblende gneiss or weakly banded amphibolite interbedded with quartz biotite gneiss. In thin section a weakly developed lepidoblastic texture can be observed in the form of alternating layers of hornblende-clinopyroxene and plagioclase. The clinopyroxene is diopsidic in composition as indicated by the chemical analysis. The plagioclase twinning is sharply defined and its composition is An 30.

Wilcox and Poldervaart (1958, p. 1348) have suggested that concordant rocks of this type are para-amphibolites derived from mafic tuffs, dolomitic shales or graywackes. The ortho-amphibolities, indistinguishable on the basis of their mineralogy and chemistry are generally recognized by their discordant relationships with the surrounding rock.

Chemically this rock shows a close similarity to the average basalt (Poldervaart, 1955, p. 134) with the exception of its higher lime content. On this basis it is believed to be a derivative of a mafic tuff or a submarine basaltic flow. In contrast to the average mafic tuffaceous sediment of the Slate Belt (Table 4, Column 2), the amphibolite is significantly lower in silica, iron, and alumina while it is higher in lime, magnesia and soda.

Sample 6 (192-N) is a quartz biotite gneiss marginal to the large pluton centered to the north of Newberry. In thin section, the rock is chiefly a granoblastic mosaic of quartz, plagioclase and microcline. The plagioclase is cloudy and partially sericitized. The microcline ex-

hibits a micrographic intergrowth with quartz. Biotite is in the form of flakes, shreads and clots generally parallel to the foliation. The clinopyroxene appears to be diopsidic and the chemical analysis indicates a substantial magnesium content. A minor amount of chlorite is present as a late alternation product along with sphene and opaque iron ores as accessories.

The chemical analysis and field relationships strongly suggest that this rock is a migmatite formed by the addition of felsic material to the mafic amphibolite country rock typical of the Charlotte Belt (Armstrong, 1941, p. 667-694). The silica, soda, and potash percentages are increased whereas the iron, lime and magnesia have decreased although still present in significant amounts and represented mineralogically by relict pyroxene and hornblende. Chemically the rock is close to the average graywacke as reported by Poldervaart (1955, p. 135) but the presence of relict minerals and the abundant evidence of metasomatism seem to preclude this alternative for the specimen analysed. However, it is possible that much of the quartz-biotite gneiss over this portion of the Piedmont does represent highly metamorphosed graywacke.

Sample 7 (277-N) is a quartz-microcline gneiss of the type which crops out extensively in the northwestern portion of the county (Plate I). Texturally and mineralogically it is similar to sample 6 (192-N), described above. The major difference between the two types is the greater microcline content of the latter. It is characterized by pink to white microcline prophyroblasts ranging up to an inch in their maximum dimension. Chemically the difference between the two rocks is seen in the greater total alkali content of the quartz-microcline gneiss and a lower soda to potach ratio (Figure 3). The magnesium content of this sample is less but the total iron is greater than in sample 6 (192-N). These differences might be attributed to variations in the chemistry of the original amphibolite from which each type was metasomatically derived.

Sample 8 (184-N) is a coarse grained, buff colored, quartz monzonite (adamellite) which occurs in the form of small isolated bodies usually on the margins of the large plutons. The presence of zoned plagioclase in these rocks as well as abundant disoriented xenoliths is interpreted as evidence for a magmatic origin. However, the precise relationship between these coarse grained buff colored plutonics and the larger masses of finer grained gray rock is obscured by poor exposures. They may represent marginal phases or separate somewhat later intrusives. They are characterized chemically by a more intermediate compositon than the adjacent gray intrusives, as evidenced particularly by the higher total iron content (Table 2). This more intermediate composition, high iron content, the presence of hornblende,

which is lacking in the central parts of the pluton, and the disoriented zenoliths all suggest marginal contamination of a magma originally more granitic in composition.

Sample 9 (284-N) is a medium grained, light gray, quartz monzonite, typical of the central parts of the massive plutons in Newberry County. Mineralogically it is characterized by zoned and extensively serictized plagioclase and by the lack of hornblende. Chemically the rock is close to the average granite in composition although it is somewhat higher in lime and lower in alumina. In contrast to sample 8,

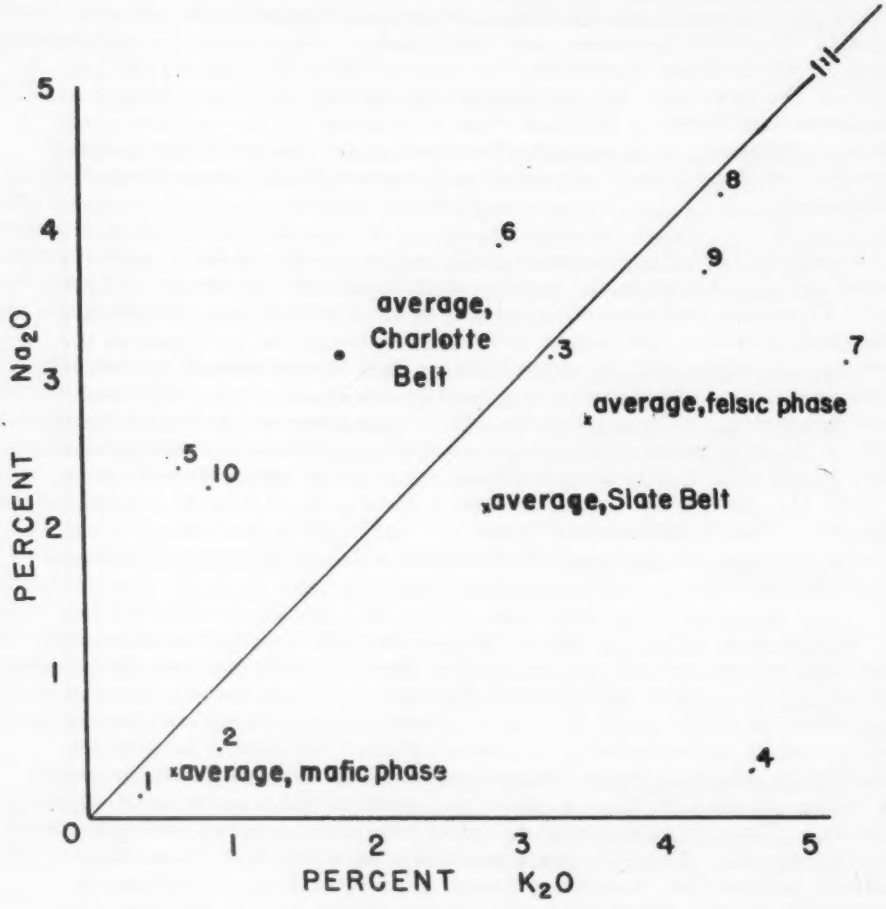


Figure 3. Soda to potash ratios of analysed samples and computed average analyses.

described above, it is generally more felsic and exhibits a lower soda to potash ratio (Figure 3).

Sample 10 (283-N) is a purplish green, hornblende gabbro from a thin arcuate dike just to the northeast of the town of Newberry (McCauley, 1960). In thin section, the major constituents are well twinned plagioclase, and fibrous amphiboles of the tremolite-actinolite type. Some clinopyroxene is present along with chlorite and biotite. The indices of refraction of the plagioclase are between 1.55 and 1.57 and its composition is inferred to be An 50.

Two other larger intrusives of the same type rock have also been discovered in Newberry County but this particular dike rock was chosen for chemical analysis because of its more homogeneous character. Its composition is very close to the average for plateau and tholeiitic basalts as reported by Poldervaart (1955, p. 134). Although these hornblende gabbros have been affected by retrogressive metamorphism, as evidenced by their mineralogy and the presence of pegmatites well within their margins, they have apparently undergone little or no change in bulk composition. The plugs and dikes of similar rock to the northwest of Newberry County in the direction of Spartanburg are increasingly altered by retrogressive metamorphism to yield dark colored schistose rocks rich in biotite. These altered mafic rocks weather into the vermiculite deposits so common in the upper Piedmont area. It is particularly interesting to note that the degree of retrogression of these late orogenic gabbros increases as the relatively young 250 million year metamorphic axis of Kulp and Eckelmann (1961) is approached. This axis apparently marks the youngest regional metamorphic event in the Piedmont and clearly postdates the emplacement of these gabbros.

AVERAGE BULK CHEMISTRY

One of the possible relationships between the Slate Belt and adjacent Charlotte Belt often suggested by workers in the Piedmont area of the Carolinas is that the high rank plutonics and metamorphics to the west and to the east (North Carolina) of the Slate Belt are upgraded metamorphic derivatives of Slate Belt rocks (Parker and Broadhurst, 1959; Stromquist and Conley, 1959). This particular suggestion is one that can be examined critically by means of a comparison of the average bulk chemistry of each belt. Engel and Engel (1958, p. 1380-1382) have shown that computed analyses derived from modal analyses are general-

Table 3. Average Mode for Felsic Phase of Carolina Slate in Volume Per Cent

	(1) JM-3 Argillite	(2) JM-4 Argillite	(3) JM-5 Meta-Dacite	(4) JM-11 Phyllite	(5) JM-12 Argillite	(6) JM-13 Argillite	(7) JM-14 Argillite	(8) JM-15 Argillite	(9) 50 N Phyllite	(10) 262 N Phyllite	(11) Average Felsic Phase
Quarts	69.8	62.0	6.0	34.0	49.0	55.0	62.0	55.0	65.0	21.1	34.9
Mica	25.0	31.0	13.0	63.0	45.0	37.0	31.0	39.0	27.0	60.3	32.6
Epidote	0.8	1.0	1.0	-	-	-	-	-	8.0	0.7	1.4
Plagioclase	1.3	1.0	38.0	-	1.0	2.0	1.0	1.0	-	-	13.0
Microcline	-	-	39.0	-	-	-	-	-	-	-	13.0
Opaques	3.0	5.0	3.0	3.0	5.0	5.0	5.0	5.0	-	17.9	4.8
Number of Counts	1200	1000	1000	1000	1000	1000	1000	1000	1000	1000	10,200

ly as accurate as actual chemical analyses, provided the compositions of the minerals are well established and reasonably uniform. With this method as a supplement to the actual chemical analyses sufficient quantitative information is presently available to attempt a first estimate of the overall average compositions of each belt.

Carolina Slate Belt

The only chemical analysis available of the lighter colored felsic phase of the "slate" is sample 3-262-N. This, however, could not be considered typical because of its abnormally high hematite content. In order to arrive at a better estimate of the chemistry of these light colored rocks ten modal analyses were obtained from the three major rock types which constitute the felsic phase. These are laminated argillites, quartz-white mica phyllites and interbedded metavolcanics. An average mode for each rock type was computed and these weighted equally to obtain an average modal analysis for the felsic phase (Table 3). The equal weight assigned each type was based on the field observation that the three rock types occur with about the same frequency in this general area. The average modal analysis was used to make a computed chemical analysis. The compositions of the mica and opaque material were obtained by a comparison between the computed and the chemical analysis of sample 262-N. Ideal compositions were used for the quartz, epidote, microcline and plagioclase. The plagioclase compositions of the samples were variable and in some cases difficult to determine so that an average value of An 50 was used. The final computed average composition of the so-called "felsic phase" is given in Column 1 of Table 4.

Two chemical analyses of the "greenschist" type phyllites were available. Since these rocks are relatively homogeneous, the average of the two (48-N, 260-N) is considered reasonably representative of the so-called "mafic phase" (Table 4, Column 2). Greenschists of the "mafic phase" are estimated on the basis of recent mapping in the Irmo Quadrangle (Heron and Johnson, 1958) and in Newberry County to constitute about one quarter of the total exposed rock. In the calculation to obtain the final average given in Column 3, the values in Column 1 and 2 were weighted according to this ratio.

In obtaining this average Slate Belt bulk composition the schistose rocks on the western margin were excluded from the computation, primarily because of the evidence for widespread metasomatism in this area. Also excluded were the late orogenic granite to granodiorite bodies which intrude the Slate Belt in many areas. Thus, the values

Table 4. Average Computed Compositions

	(1) Average Slate Belt Felsic Phase	(2) Average Slate Belt Mafic Phase	(3) Average Slate Belt Composition	(4) Average Charlotte Belt Composition
SiO_2	64.8	54.6	62.3	56.99
FeO	0.3	9.3	2.5	4.87
Fe_2O_3	5.4	7.1	5.8	3.41
Al_2O_3	20.5	13.6	18.8	11.92
CaO	2.1	5.1	2.8	9.90
MgO	-	4.3	1.1	7.08
MnO	-	0.2	-	0.11
Na_2O	2.7	0.3	2.1	3.15
K_2O	3.5	0.6	2.8	1.77
H_2O	0.5	2.6	1.0	0.14
CO_2	-	-	-	0.09
TiO_2	0.7	1.5	0.9	0.85
	100.5	99.2	100.1	99.28

determined approximate the chemical character of the rocks before the last period of plutonic activity.

The margin for error in this calculation is substantial, particularly in regard to the estimates of the percentage of each rock type actually present. However, this first estimate does indicate that the gross composition of the Slate Belt in central South Carolina is not rhyolitic or felsitic as has often been assumed. Rather, it appears to be andesitic as can be seen in the comparison with rocks of similar composition given in Table 5 although the average is lower in lime, magnesia and alkali than the intermediate igneous rocks. This composition is in distinct contrast with the considerably more mafic character of the adjacent Charlotte Belt discussed under the next heading.

Table 5. Average Compositions

	(1) Average Slate Belt Bulk Composition	(2) Average Cordilleran-Appalachian Igneous Rock*	(3) Average of 87 Andesites*	(4) Average Igneous Rock*	(5) 635 Intermediate Igneous Rocks*	(6) Average of 49 Andesites*
SiO_2	62.3	62.4	60.3	60.1	54.9	54.6
FeO	2.5	3.3	3.1	3.9	5.2	5.5
Fe_2O_3	5.8	3.0	3.4	3.1	3.3	3.5
Al_2O_3	18.8	15.9	17.5	15.6	16.7	17.4
CaO	2.8	5.1	5.9	5.2	6.6	8.0
MgO	1.1	3.0	2.8	3.5	3.8	4.4
MnO	-	0.2	0.2	0.1	0.2	0.2
Na_2O	2.1	3.4	3.6	3.9	4.2	3.7
K_2O	2.8	2.7	2.1	3.2	3.2	1.1
H_2O	1.0	-	-	-	-	-
CO_2	-	-	-	-	-	-
TiO_2	0.9	0.7	0.8	1.1	1.5	1.3

*Averages from Poldervaart, 1955, p. 134.

Charlotte Belt

Any attempt to estimate the original bulk chemistry of the Charlotte Belt in this area is complicated by the presence of widespread plutonic activity. Since this study is primarily concerned with the character of the metamorphic rocks in contrast to those of the Slate Belt, the quartz monzonites, migmatites and late orogenic gabbros were excluded from the computation.

Field and thin section studies definitely suggest that the oldest rock type present is hornblende gneiss or amphibolite. It is believed that these rocks have been extensively altered by solutions emanating from the granitic plutons into migmatites, quartz-biotite and quartz-microcline gneisses. The unmigmatized amphibolites (Table 2, Column 3) then, are the only rocks present that are truly representative of the pre-orogenic character of the belt. To these might be added some or all of the quartz-biotite gneiss (Table 2, Column 6) which, as has been noted, is close in composition to the average graywacke and could be representative of the sediments interbedded with the submarine basalts or mafic tuffs which gave rise to the amphibolites.

An average of the quartz-biotite gneiss and the amphibolite then would provide a reasonable estimate of the original character of the Charlotte Belt. This is given in Table 4, Column 4; and comparison with Column 3 indicates that the Charlotte Belt metamorphic rocks are considerably lower in silica, alumina, potash and water; and higher in lime, magnesia, and soda than the average Slate Belt rock. Also, the soda to potash ratio of the Charlotte Belt rocks is considerably greater than for those of the Slate Belt (Figure 3).

In general, then, it can be said that the average original character of the Charlotte Belt metamorphic rocks was considerably more mafic than the rocks of the Slate Belt which on the average are intermediate in composition. This pronounced chemical dissimilarity cannot be the result of increasing metamorphic rank, if the dubious "basic front" concept is not invoked. It is, therefore, considered very improbable that the rocks of the two belts in central South Carolina are the stratigraphic or pre-metamorphic correlatives of one another, as has often been suggested.

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THE STRATIGRAPHIC PALEONTOLOGY OF THE CHICKAMAUGA GROUP OF THE RED MOUNTAIN AREA, ALABAMA

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ABSTRACT

On the basis of the paleontological evidence, Unit I of the Chickamauga group is Chazy, Units II and III are, respectively, Lower and Upper Black River; and Unit IV is Trenton in age. Unit I is correlated with the type Lenoir (restricted) of Lenoir, Tennessee, and the Lenoir limestone of Cahaba Valley of Alabama.

Unit II is correlated with the Little Oak limestone-Athens shale lateral sequence of the Cahaba Valley; the Farragut-Tellico limestone interval of East Tennessee; the Ordovician strata in the Central Basin of Tennessee up through the Ridley limestone; and the Edinburgh formation of Virginia. Based on the fauna present, the Unit is considered to be Lower Black River in age.

Unit III of the Chickamauga group is correlated with Unit 3 of the Middle Ordovician in East Tennessee. Unit III appears to be closely related to the Carter limestone member of the Lowville formation of the Central Basin of Tennessee.

It is suggested that most probably the contact relationship between Unit III and Unit IV is unconformable. This erosional interval is probably represented in the Central Basin of Tennessee by the Tyrone formation.

The paleogeography of the Alabama area during Chazy, Black River and Trenton time is reviewed.

INTRODUCTION

Until recent years the paleontology of the Paleozoic strata of the Southeastern United States, and, in particular, the Ordovician strata in the Birmingham Valleys (Jones and Opposum Valleys and their northeast extension) and the Cahaba Valley had been studied only at the reconnaissance level. The publication in 1956 of CHAZY AND RELATED BRACHIOPODS by G. A. Cooper may well mark the start of a new era in the study of the Paleozoic stratigraphy of the southeast and, in particular, Alabama.

In previous publications (Rogers 1960, 1961), the writer suggested a subdivision of the Chickamauga limestone. This work led to the revision of the name Chickamauga limestone to Chickamauga group.

Each Unit (I, II, III, and IV) of the Chickamauga group as previously defined (Rogers, 1960, 1961) should be examined separately. The writer feels, as does John Rodgers[1], that these informal terms undoubtedly represent in each case one and perhaps more formations. Subdivision of these Units on paleontological and lithological grounds should provide valuable data on: 1) the beginnings of the Appalachian geosyncline; 2) the Tennessee Basin; and 3) perhaps a reconciliation of at least a portion of the plethora of the formation names that have recently been applied to Ordovician strata.

A word of caution relative to the Ordovician system in Alabama seems appropriate at this point. These strata reflect the influence of two distinct paleoecologic provinces, 1) that west of the Central Basin on the continental plate including the area west of the Cincinnati axis and 2) the miogeosynclinal portion of the Appalachian geosyncline to the east of the Cincinnati axis. Paleoecologic sedimentary influences of both provinces are to be found in Alabama.

PALEONTOLOGY AND CORRELATION

Chazy Stage---Unit I

Rostricellula pristina occurs in the type Lenoir limestone of Ten-

1. Personal communication.

nessee and in Unit I of the Chickamauga group (Gate City section) of Alabama (Rogers, 1960, p. 102). This species is an index to the Lenoir limestone (Cooper and Cooper, 1946, p. 74) (for restriction of type Lenoir limestone, see Cooper, 1956, p. 72). The presence of Rostricellula, Anolotichia, Pachydictya, Liospira, Helicotoma, Camarocladia, Lecanospira and Sinuopea in Unit I of the Chickamauga group in the Birmingham Valley and in the Lenoir limestone of Cahaba Valley are considered by the writer to show correlation between these two units.

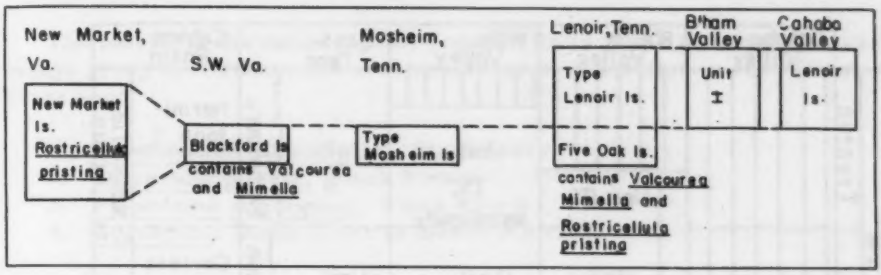


Figure 1: Stratigraphic Position of New Market and Blackford Limestones Relative to Type Mosheim and Lenoir Limestones.

The presence of Rostricellula pristina and Rostricellula cf. plena in Unit I shows a relationship of this Unit to the Mosheim and Five Oaks limestones in Northern Virginia (Rogers, 1960, p. 102). The relationship of the Unit to the restricted type Lenoir limestone would also relate Unit I to the Lincolnshire limestone (Rogers, 1960, p. 103). Faunally, the Lenoir limestone is related to the Loysburg formation and overlying Clover limestone of Pennsylvania. By implication Unit I in Alabama is related to these two formations.

In Unit I of the "Chickamauga limestone", as defined by Rodgers (1953, p. 35), a basal chert conglomerate is common (Attalla chert conglomerate). The presence of a basal chert conglomerate has been shown (Rogers, 1960, 1961) to be true of the Chickamauga group in Alabama. Therefore, the bases of these two stratigraphic units are probably at the same horizon. (For possible exception to the occurrence of conglomerates, see Kellberg and Grant, 1956, p. 716 and Rogers, 1960, p. 30).

The top of Unit I in both Alabama and east Tennessee areas is drawn at a laterally persistent cherty limestone horizon. No Chazy equivalents are present in the Central Basin of Tennessee with the possible exception of the Wells Creek formation. The exact age of the base of this formation is not known.

Genera occurring in Unit I in Alabama such as Hesper-orthis, Sowerbyella, Amplexopora, Leperditia, Isochilina, and Bucania range from the Chazy to the Trenton stage (Rogers, 1960, Pl. XI, p. 134). At least six genera occurring in Unit I of the Chickamauga group are restricted to the Chazy. Other genera reported (Rogers, 1960, Pl. XI, p. 134) range from Chazy to Black River; indeed, a number range only from Chazy to Lower Black River. These taken in conjunction

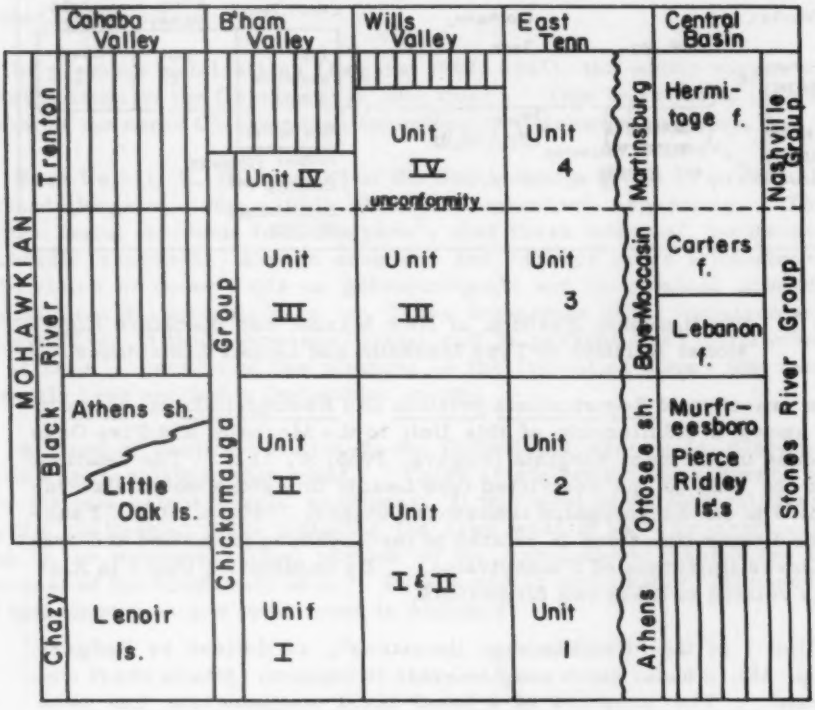


Figure 2. Intra-Regional Correlation of the Chickamauga Group in Cahaba Valley, Birmingham Valley, and Wills Valley (based on the writer's interpretation).

with the overlapping ranges of other genera, suggest the Chazy age of this unit.

In summary, Unit I of the Chickamauga group in Alabama, on the

basis of stratigraphic position and fauna, is shown to correlate with Unit I of the "Chickamauga limestone" in east Tennessee and the Lenoir limestone of Cahaba Valley, Alabama, (Rogers, 1960, Fig. 6, p. 85, and Pl. VII p. 64). Regional correlations of Units I, II, III, and IV are shown in Figure 2. This figure has been previously published by the writer in 1960 and 1961.

Black River Stage---Units II and III

The fossils in the following list occur in Units II and III of the Chickamauga group of Alabama and are considered by the writer to show Black River age:

1. Strophomena planumbona, Black River;
2. Camerella plicata, Black River;
3. Pionodema subaequata, Black River;
4. Zygospira, Black River to Lower Silurian.

The following genera which occur in Units II and III are Black River or mainly Black River in age:

1. Stromatocerium, Black River to Richmond;
2. Escharopora, Lower Black River to Maysville;
3. Homotrypella, upper Black River to Richmond;
4. Pachydictya, largely Black River to Middle Silurian;
5. Illaenus, largely Black River to Silurian;
6. Raphistomina, largely Black River;
7. Streptelasma, Black River to Devonian;
8. Carabocrinus, lower Black River to Richmond.

From its ease of identification and its abundance, the best guide to the Black River stage of this portion of the Chickamauga group is Streptelasma sp. and Leperditia fabulites. Camarotoechia (Rostricellula), a guide to the Black River in New York, is found in these two units.

In east Tennessee, the top of Unit 3 of the "Chickamauga limestone" is marked by a bentonite horizon. The top of Unit III of the Chickamauga group in Alabama is similarly delimited. The top of Unit I in Alabama and Unit I in east Tennessee has been shown to be the same. On the bases of the similar bentonite horizons at the upper contacts, the similarity of lithology of Units II and III in east Tennessee and Alabama, (Rogers, 1960, 1961), and the common occurrence of Stromatocerium and Hesperorthis in both areas, the writer concludes that Units 2 and 3 in east Tennessee and Units II and III in Alabama are correlatives. These units in both areas are Black River in age and contain those

strata which, in the Basin of Tennessee, are referred to as the Stones River group (Figure 2).

On the bases of the presence of the following forms, Unit II of the Chickamauga group is placed by the writer in the lower Black River:

Dystactospongia sp.	Rostricellula
Illaenus fieldi	Eotomaria sp.
Tetradium cellulosum	Lophospira sp.
Leperditia fabulites	Maclurites sp.
Gonioceras sp.	Hesperorthis tricenaria
Lichenaria carterensis	Zygospira recurvirostris

Fascifera subcarinata

Unit III is assigned an upper Black River age on the bases of the following forms that have been collected from this unit:

Rafinesquina trentonensis	(Wilderness Trenton; Hermitage. Butts, 1926, p. 130)
R. aff. R. minnesotensis	(Ridley horizon?; Butts, 1926, p.130)
Resserella multisecta	(Eden group; Butts - Wilderness to Trenton
Hesperorthis tricenaria	(Lebanon and Trenton horizon)
Strophomena incurvata	(Basal Trenton, Butts, 1926, p. 130)
Sowerbyella curdsvill-. . ensis	(Basal Trenton, Butts, 1926, p. 130)
Opikina deltoides	(Ridley and Basal Lebanon, Butts, 1926, p. 130)
O. septate	(Lebanon, Butts, 1926, p. 130)
O. transitionalis	(Wilderness)
Rhynchotrema increbescens	(Trenton, Butts, 1926, p. 130)

Similar ages are then assigned to the correlative units in east Tennessee. In east Tennessee, Rodgers (1953, p. 66) correlates Unit 3 with the Moccasin and Bays formations in the upper Wilderness (Black River). The Bays formation, as recognized by G. A. Cooper, extends into the Trenton.

Unit II in the Birmingham Valley, is correlated by the writer with the Little Oak limestone-Athens shale sequence in Cahaba Valley, Alabama (Rogers, 1960, p. 110). The Athens shale is considered by the writer (see also G. A. Cooper, 1956) to represent a southeastern shale facies of the Little Oak limestone.

This sequence is correlated by the writer to Unit II of the Chickamauga group in the Birmingham Valley largely on the basis of lithology. If correct, this correlation substantiates the lower Black River age of

the Little Oak limestone in Cahaba Valley. At Attalla, Alabama (Rogers, 1960, p. 172-174), a bentonite horizon (lower Black River, Butts, 1926, p. 113) has been observed by the writer in Unit II. It has not been seen in Jones Valley.

G. A. Cooper (1956, p. 75) relates the Little Oak limestone to the Arline formation, which he says is the cobbly limestone equivalent of the Athens shale. The Pratt Ferry formation is an aspect of the Little Oak limestone. Cooper (1956, p. 75) correlates the Little Oak limestone and the Arline formation with the Effna formation and the lower Edinburgh formation of Virginia. The Effna and lower Edinburgh are considered by the writer to be lower Black River (Rogers, 1960, p. 101, 110). On the bases presented above, (lithology and stratigraphic position), the Little Oak limestone would correlate with Unit II as defined by the writer. Nidulites sp. and Orthis crassicosta, which Butts (1926, 114) reports from the Little Oak limestone, are also found in Unit II.

The relationship of Unit II to the Central Basin sequence of Tennessee is shown in the following faunal list:

Pionodema subaequata
Sowerbyella pisa
Rafinesquina deltoidea
Strophomena incurvata
Hesperorthis tricenaria
Pionodema stonensis
Escharopera subrecta
Mesotrypa sp.
Illaenus fieldi
Dystactospongia sp.
Stromatocarium rugosum

(For additional correlation on the basis of fauna, see Rogers, 1960, p. 111.)

At Gate City, Alabama, G. A. Cooper (1956) describes a section of the Chickamauga group. In this section, he recognizes representatives of the Lebanon, Carters, and Curdsville limestones; these are Wilderness (upper Black River) and Trenton in age. Butts (1926) worked in the same locality. He (1926, p. 124, 126, 128) described the following forms from the basal "Chickamauga limestone" at Gate City, to which he assigned a Black River age:

Lophospira bicincta	(Ridley or basal Lebanon horizon)
Lophospira perangulata	(Murfreesboro limestone; Ridley or basal Lebanon.)

Pachydictya robusta	(Probably Ridley or Pierce horizon)
Dekayella ridleyana	(Pierce or Ridley horizon)
Carabocrinus sp.	(Black River Horizon)
Eotomaria prisca	(Black River Horizon)
Cliftonia occidentalis	(Ridley Horizon)
Refinesquina aff. R. minnesotensis	(Ridley Horizon)
Strophomena incurvata	(Ridley Horizon)
Carocladia sp.	(Early Black River, Lowville)

These species have been found by the writer in the Gate City section (Fig. 3)

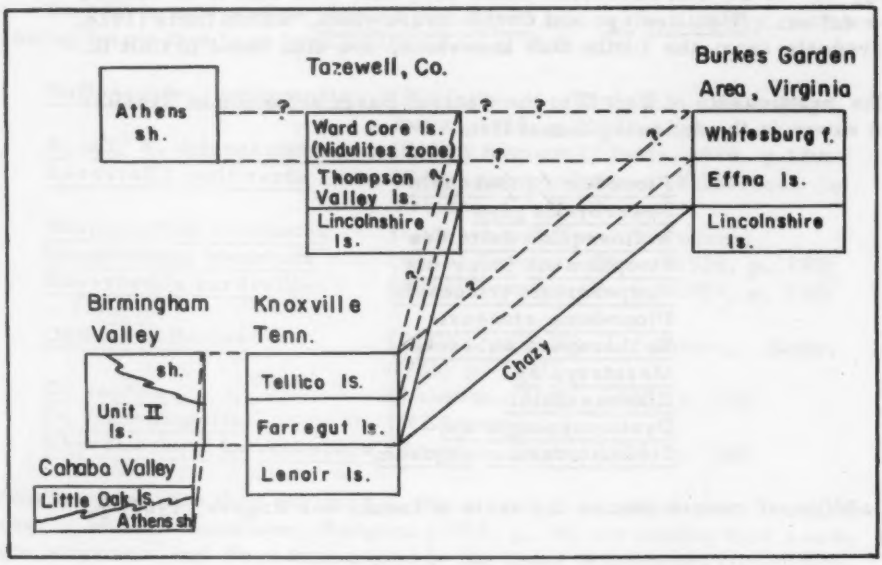


Figure 3. Correlation of Basal Black River Formations.

In the Cahaba Valley, the Athens (Columbiana) shale is overlain by the Fort Payne chert of Mississippian age. The lack of younger Ordovician strata in this area may be due to the low-angle thrust fault, or, as suggested by many, erosion prior to Mississippian times.

Unit III of Alabama correlates with Unit 3 of east Tennessee. This Unit is more closely related to the Carters limestone member of the Lowville formation then it is to the Lebanon limestone of the Central

Basin of Tennessee. The following forms reported by Wilson (1949, p. 51) as characteristic of the Carters, occur in Unit III in Alabama:

Streptelasma sp.
Tetradium cf. T. cellulosum
Rhinidictya nicholsoni
Hesperorthis tricenaria
Zygospira recurvirostris

In addition, the Carters limestone is characteristically massively bedded with local cross-bedding. These are the predominant lithologic characters of Unit III.

Rodgers (1953, p. 91-92) suggests that the lower and middle parts of the "Chickamauga limestone":

> ". . . correspond essentially to the Stones River group of Middle Tennessee and represent the Black River and probably parts of the Chazy and Trenton stages of the standard New York sequence of the Middle Ordovician series."

The specific correlations as suggested in the above paragraphs and in previous publications (Rogers, 1960, 1961) are shown on Figure 4.

Trenton Stage---Unit IV

On the basis of the following fossils collected by the writer, this unit is considered to be closely allied to the Martinsburg shale in Tennessee and Virginia and to the Hermitage formation in the Central Basin of Tennessee:

Rafinesquina hermitagensis	(Hermitage)
R. aff. R. trentonensis	(Trenton)
Resserella multisecta	(Martinsburg)
Sowerbyella curdsvillensis	(Martinsburg)
Rhynchotrema increbescens	(Nealmont, Carters, Tyrone, Egglestone, Oranda)
R. capax	(Richmond Stage)
Zygospira recurvirostris	(Nealmont, Carters, Tyrone, Oranda, Collierstown)
Hebertella sinuata	(Martinsburg and Cathys)
Amplexopora sp.	(Martinsburg)
Sinuites cancellatus	(Martinsburg)

On the basis of the preponderance of fauna of upper Trenton age, and the lack of a distinct Tyrone fauna, the writer suggests that an unconformity separates Unit III from Unit IV (Figure 5).

Field conditions (masking by slumpage from the overlying Silurian, Red Mountain formation, similar lithology of Unit IV with the lower Red Mountain formation) have made Unit IV very difficult to delimit.[2] This is particularly true in the northwestern portion of the area of this investigation.

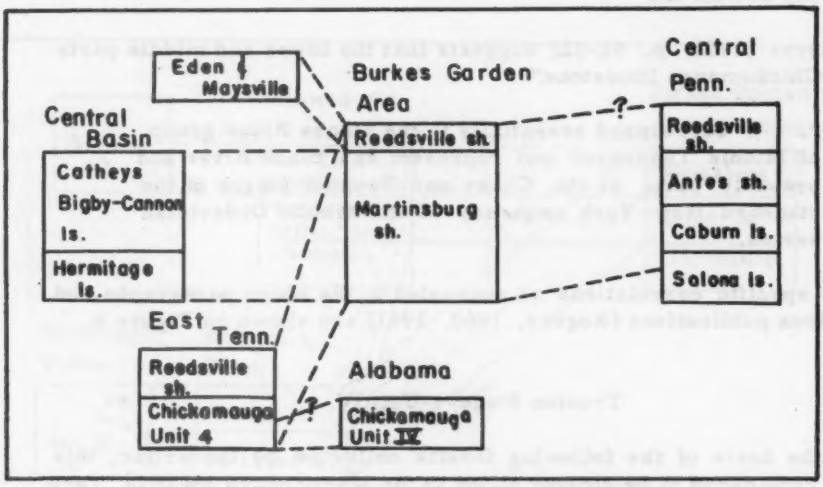
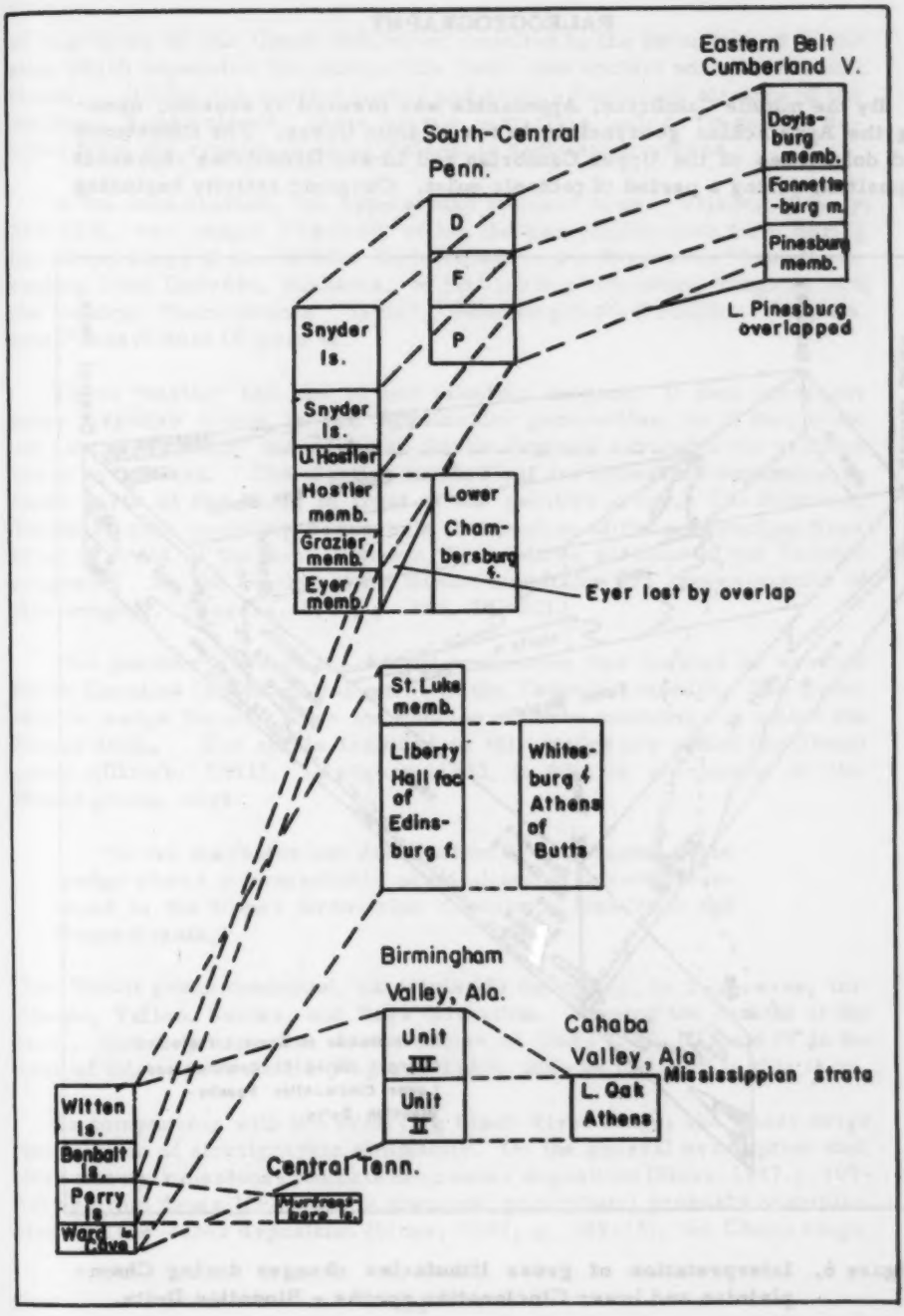


Figure 5. Correlation of the Martinsburg Shale and its Equivalents

2. In many areas of the Birmingham region, mapping strictly on the basis of lithology has resulted in the inclusion of portions of Unit IV in the Red Mountain formation

Figure 4. Black River Correlations in Central and Northern Regions of the Eastern United States.


Eastern Belt
Cumberland V.
South-Central
Penn.
Doyts-
burg
memb.
Fannette
-burg m.
Pinesburg
memb.
L. Pinesburg
overlapped
D
F
P
Snyder
ls.
Snyder
ls.
U. Hostler
Hostler
memb.
Grazier
memb.
Eyer
memb.
Lower
Cham-
bersburg
f.
Eyer lost by overlap
St. Luke
memb.
Liberty
Hall fac.
of
Edins-
burg f.
Whites-
burg &
Athens
of
Butts
Birmingham
Valley, Ala.
Unit
III
Unit
II
Cahaba
Valley, Ala
Mississippian strata
L. Oak
Athens
Witten
ls.
Benbalt
ls.
Parry
ls.
Ward
Cave
Central Tenn.

PALEOGEOGRAPHY

By the middle Cambrian, Appalachia was lowered by erosion, opening the Appalachian geosyncline to the Atlantic Ocean. The limestones and dolostones of the Upper Cambrian and Lower Ordovician represent deposition during a period of tectonic quiet. Orogenic activity beginning

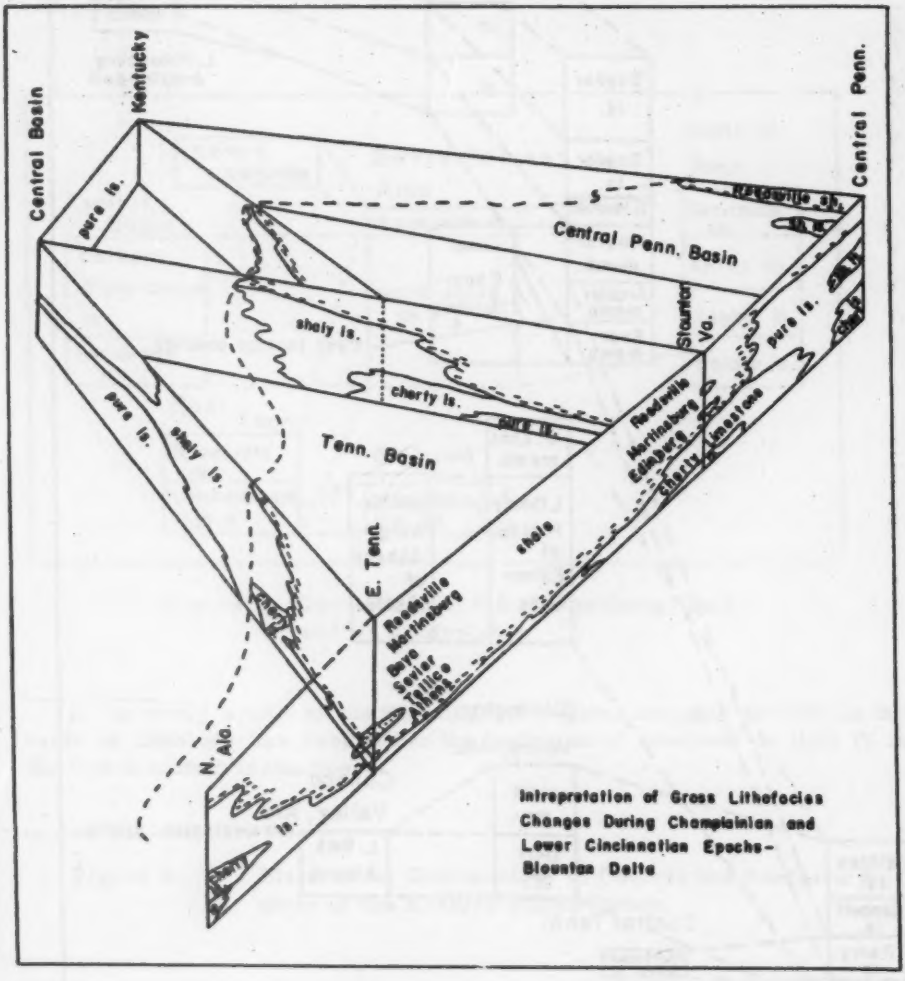


Figure 6. Interpretation of gross lithofacies changes during Champlainian and lower Cincinnatian epochs - Blountian Delta.

at the close of the Chazy sub-epoch resulted in the formation of island arcs which separated the geosyncline from open contact with the Atlantic Ocean. Unlike the earlier Lower and Middle Cambrian clastics of the Southern Appalachians, these clastic materials include fragments derived from the erosion of older Paleozoic sedimentary rocks.

In the area studied, the Appalachian foreland area, (Wilson, 1949, p. 332-333), two major "basins" within the geosyncline took form during the Chazy stage of the Middle Ordovician: the Tennessee "basin" extending from Gadsden, Alabama, to just north of Staunton, Virginia; and the central Pennsylvania "basin", extending from Staunton, Virginia, into Pennsylvania (Figure 6).

These "basins" had one of two possible origins: 1) they represent more negative areas in the Appalachian geosyncline, or 2) they were not actually "basins" but areas of clastic deposits derived from positive areas to the east. The clastics masked out any limestone deposition in those parts of the basin in front of the positive areas. The Staunton, Virginia, area probably represents that portion of the geosyncline floor lying in front of the area between the positive portions of the Taconic orogeny. To the southwest the Blount mountains are representative of this orogeny. (Rogers, 1960, p. 134, Pl. XI).

The positive area of the Blount mountains was located in western North Carolina (the Blountian phase of the Taconic orogeny). The great clastic wedge formed from the erosion of these mountains is called the Blount delta. The strata included in this wedge are called the Blount group (Ulrich, 1911). Rodgers (1953, p. 93), in discussion of the Blount group, says:

> "In the character and distribution of rock facies, this wedge shows a remarkable parallelism to a wedge centered in the Upper Ordovician deposits of New York and Pennsylvania."

The Blount group contained, as originally described, in Tennessee, the Athens, Telico, Sevier, and Bays formation. Keeping the context of the term, Blount group, the clastic facies of Units I, II, III, and IV in the area of this report should (Rogers, 1960), also be included in this term.

In comparison with the overlying Black River stage, the Chazy stage was a time of stratigraphic simplicity. On the general assumption that dark cherty limestones indicate deep water deposition (Sloss, 1947, p. 109-13) and that dense limestone (a chemical percipitate) probably exemplifies shallow water deposition (Sloss, 1947, p. 109-13), the Chazy stage

of Alabama gives an example of marine onlap. This onlap sequence is cherty limestone, argillaceous limestone, and pure limestone. This sequence shows a progressive increase in depth of water from west to east. On this basis, the lower part of Unit I, generally dense limestone, of the Birmingham and Cahaba Valleys are shallow water deposits in the foreland province of the Appalachian geosyncline. A gradual rise in sea level is possibly indicated by the cherty limestone of the upper part of Unit I and by the Little Oak limestone.

The Chazy stage was brought to a close in Alabama and the eastern United States by a retreat of the sea to the south. (Note unconformity at top of the Lincolnshire and its complete absence in central Pennsylvania, Rogers, 1960, p. 104).

In Alabama, there is no evidence that would lead to the conclusion of cessation of deposition at the close of the Chazy stage. (For the contrary opinion, see Butts, 1926, p. 30.) In the Central Basin, the Chazy interval is represented by an unconformity.

By Black River time, the character of the Appalachian foreland had changed to a shallow sea with many scattered, low island of early Black River material. These islands of clastic material probably represent areas where streams moving across the Blount delta extended deposition of clastics out into the geosyncline. (Grant and Kellberg have suggested a similar origin for the Attalla chert conglomerate.)

Trenton time up through the Lower Silurian was a continuation of the sedimentary environment established during the Black River time.

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RECENT ROOT CASTS IN SEDIMENTS OF THE APALACHICOLA DELTA, FLORIDA*

by

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ABSTRACT

Old dune sands in the coastal portions of Apalachicola Bay, Florida, contain numerous casts of organic carbon and iron oxide cemented sand which are apparently the record of roots of a previous forest cover. The stratigraphic positions and carbon 14 dates of some of these indicate that they formed at least 1500 years before present and as much as 3800 years before present.

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INTRODUCTION

During the summer of 1959 John Kofoed of the Florida State University Department of Geology and Floyd Savins of the California Research Corporation noticed sedimentary structures of possible organic origin along coastal roads near Carrabelle, Florida (Figure 1). The tentative conclusion regarding the origin of these features was that they represented some form of root cast. Pilkey subsequently examined the physical and chemical characteristics of the features at the suggestion of Gorsline. In addition, radiocarbon dates were obtained through the courtesy of the Exploration Department of Humble Oil and Refining Company and H. N. Fisk, Chief of Geologic Research for that company. Frank Andrews of Arrowhead Geoservices Company very kindly made available information obtained during his own field studies in the area. H. G. Goodell and J. K. Osmond offered useful criticisms of the manuscript.

Paleontologists and stratigraphers have long known of various structures preserved in sedimentary rocks which appear to be of organic origin but which cannot readily be assigned to particular biological groups. Hantzschel (1952) has reviewed the synonyms of some particular types known as Halymenites (Sternberg, 1833) and Ophiomorpha (Lundgren, 1891).

These last have been variously described as fossilized root casts, burrows, or algal masses, and have been reported from many parts of the world and from sediments and sedimentary rocks of Mesozoic and Cenozoic age (Hatai, 1938; Hantzschel, 1952; Shrock, 1948). Most share the common characteristics of an outer shell or case often with an irregular or knobby surface and filled with sediment which is generally similar in its characteristics to adjacent materials outside or above the structure. The composition has been reported as calcareous, ferruginous and carbonaceous. Emery (1950) has reported opaline root casts in Pleistocene dunes on the Southern California marine terraces.

The description and discussion of the features found in the Apalachicola area should be of general interest because of their relatively recent age and their well defined relationships with contemporary sediments and physiography. They also provide some insight into the rate at which features of similar type may have formed in the geologic past.

DISCUSSION

The area in which the present study centers is Apalachicola Delta

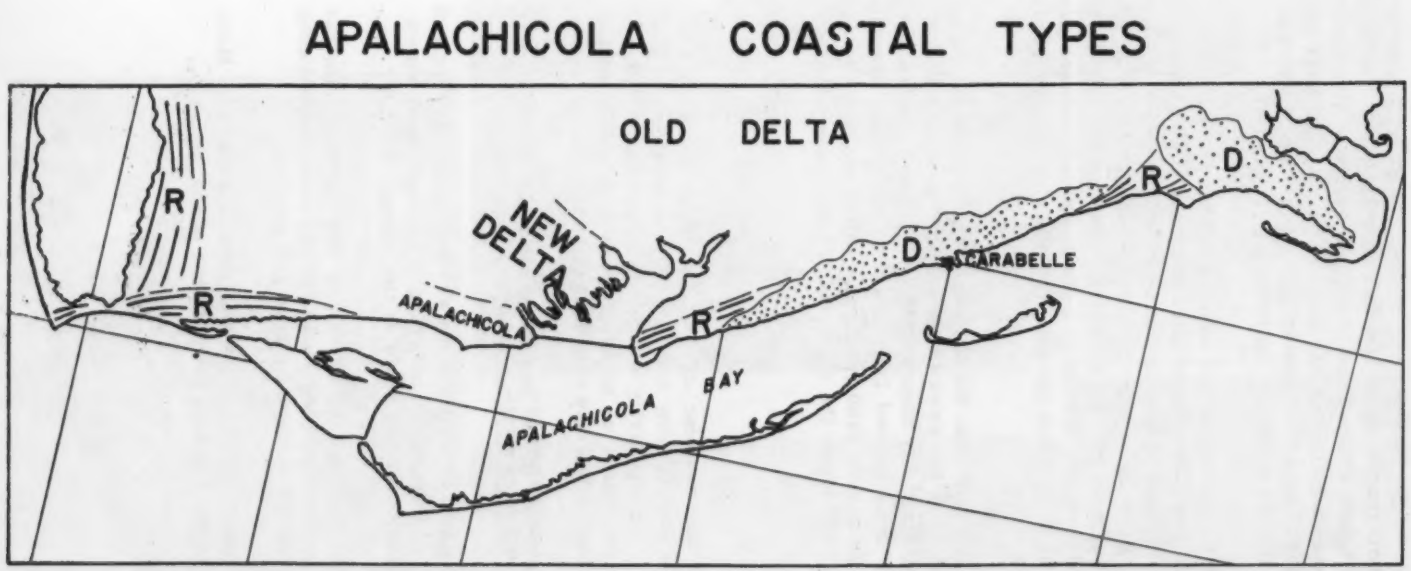

Figure 1. Generalized coastal physiographic types in the area of Apalachicola Bay, Florida. Photographs in Figure 2 were taken in the approximate location of Carrabelle. The letters indicate old dune fields (D), delta surfaces, and beach ridges (R).

(Figure 1). Aerial photographs show low flat marshlands of the delta surface fronted by old "beach ridges" and irregular areas of hummocky topography that have been identified as old dune fields. The positions of these two physiographic types are shown in Figure 1 and the details of the cross bedding of the old dunes is illustrated in Figure 2.

The ridges and dunes may represent several distinct sedimentation periods. The dunes in the Oklochonee area truncate and obscure the old and poorly preserved linear ridges to the west. The dunes west of Carrabelle, Florida (Figure 1) appear to have an equally complex relationship with several groups of ridges which make up the coast adjacent to the present Apalachicola Estuary. Both sets of features are sharply defined and delineated from the interior marshes and lowlands of the old deltaic surface.

Field observations indicate that these older land forms are being truncated by wave erosion at the present shore and the sand redistributed into parts of the adjacent bay floor. The older dunes and ridges, which consist of weakly consolidated iron stained sand, are overlain by a blanket of loose white quartz sand ranging in thickness from two to ten feet or slightly more. Between the orange and white sands the con-

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Figure 2. A. These cross sections of root casts in old dune sand show the hard brown casings and the clean white sand fillings. Irregularity of the sections is partly due to uneven excavation of an axial plane through the structures. Approximately nine feet of section is exposed.

B. Cross bedding in the old dune sands is illustrated as are the resistant dark knobs of the root casts.

C. The circular and oval shapes are horizontal sections of the casts. Occasional merging of casts is also shown. The pen indicates the scale of the casts.

D. The outer surfaces of the casts are shown. Laminar bedding in the overlying sediment has been drifted over an old road cut surface by wind and gravity.

E. A living sand pine and its tap root is pictured. Note the fine radial rootlets growing out of the tap root.

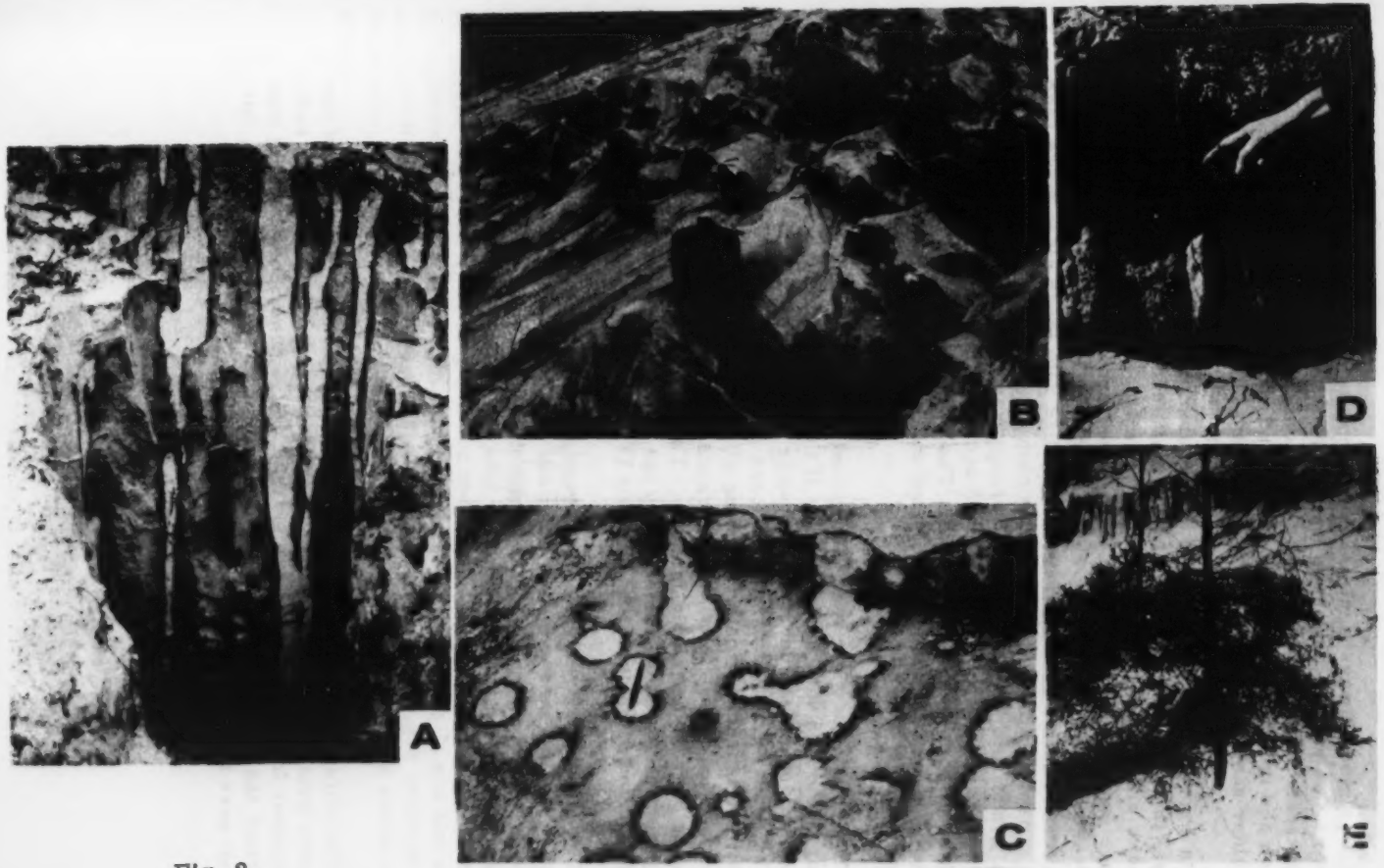

Fig. 2

tact is almost always a clean and sharp one except in a few instances where a thin and discontinuous layer of dark carbonaceous debris is also present. The two sand types differ only in their degree of consolidation and color. Probably the white sand was derived by reworking of the older sands and subsequent transport.

In exposed faces of the old dunes along much of the Apalachicola coast, the observer is struck by the multitude of white and dark brown streaks and resistant knobs which typically stand out from the light orange sand body. Dissection of these features (Figure 2) reveals that they are tubular sheaths or casts of moderately-to-well consolidated iron oxide and carbonaceous material filled with loose clean white sand. The consolidated walls of the tubes abruptly contact the white sand filling, grade into the surrounding orange sand, are truncated at their tops by the contemporary white sand and range in wall thickness from a fraction of an inch to a few inches. The white sand in the tubes is identical to the surface sand (Table 1) and merges with it with no trace of a discontinuity.

Typically, the white sand filling contains bits of carbonaceous matter or is mottled with this debris as if the tubular opening was filled by mixed sand and plant debris. The outer surfaces of the cases are spotted by small white and pale tan patches which may represent the original site of secondary rootlets coming off the main tap root. In vertical cross section small tubes often branch away from the main cast for a distance of from one to six inches. The shapes, cross sections and small rootlets passing diametrically out from the main tube or root are all duplicated in modern root systems (Figure 2).

The brown to dark brown casts vary in length from two feet to over twenty. Their diameters vary from one inch to a foot and they are circular or oval in plan. They are frequently less than a foot apart (much closer than the average present day tree cover) and in places two or three may merge together. The tubes become gradually narrower with depth and are slightly sinuous in their essentially vertical development. The features are always developed to the same degree and no intermediate forms are present in the sediment mass.

The uniformity of the features would argue that the formation of the features went to an end stage before the present surficial tree and sediment cover formed. In the exposures where dune cross bedding was exhibited the bedding was not significantly disturbed by the cases, but did not pass through the casts.

Table 1. Sedimentological and Mineralogical Characteristics of Old Dune Sands and White Sands

Sample No.	Mean diam. (ϕ)	Sediment type
1	1.8	White sand
2	2.0	Yellow sand
3	2.4	Yellow sand
4	2.6	White sand

Sample No.	Wt. % Heavier Than 2.90	Sediment type
1	0.164	White sand
2	0.136	Yellow sand
3	0.153	Yellow sand
4	0.213	White sand

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	White Sand		Yellow Sand	
Sample No.	1	4	2	3
Opaques	26	42	25	20
Kyanite	26	13	36	28
Rutile	5	12	6	12
Starolite	4	8	9	9
Tourmaline	8	5	5	9
Pyroxene	2	2	1	4
Zircon	8	4	0	3
Apatite	7	3	0	0
Sillimanite	6	3	4	0
Others	8	8	14	7

Probably the growth of the old vegetation occurred after the dunes had formed. If the original roots of the trees grew upwards as dunes formed around them (as often occurs in present day dunes) then development of well defined cross bedding would not be expected.

Discussion of the pattern of the features with R. K. Godfrey of the Department of Biological Sciences at Florida State University has indicated that the greater density of the casts as compared to the modern cover may not be of particular significance. For example, Sand Pines often reseed themselves following fires and grow in profusion until the pressure of the nutrient demands of the adult trees begins to exert a selective effect. The natural forest fire may also serve as an agent for the initial destruction of a woods and the subsequent recovery of the trees might be slower then dune encroachment, thus creating a hiatus in which surface erosion might occur (Cooper, 1961).

In those localities where the casts can be traced to their base they sometimes terminate or cut through a well consolidated black sand layer which is located near present sea level. This layer is two to five feet thick and appears to be cemented with a mixture of iron oxides and carbonaceous material. The black sand layer may represent an accumulation of organic and inorganic materials at the upper level of the old water table after leaching removed it from the surface sediment. The black layer contains carbonaceous impressions of small molluscs in the coastal area of St. Vincent Sound and thus may be of marine origin here. A clay layer in the sequence contained driftwood fragments which were found to be radiologically "dead" (+37,000 years before present).

Radiocarbon dates were obtained for the carbonaceous material in cast from the location indicated on Figure 1, and for shells taken from an Indian midden in the same general locality. The midden material appears to lie over the orange sand and completely in the surfucial white sand. The dates are 3825- 135 and 1250 - 100 years before present, respectively.

The dated midden material and the lack of casts in the present sediment argue that the development of the present plant and sediment system is at least 1200 to 1500 years old.

Recent studies of cheniers and beach ridges of the western Louisiana and Texas coast (Gould and McFarlan, 1959) seem to support an initiation of the older elements of these linear trends at about 4000 years before present. Radiocarbon dates obtained from the base of the six or seven feet of carbonate sediment deposited in Florida Bay also

approximate 4000 years B.P. (Ginsburg, 1956). The accumulation of evidence from various Gulf coastal sites would indicate that the last rise of sea level started about 4000 to 5000 years ago and was of the order of five or six feet. Locally, the dunes and ridges may date from this lower stand. The development of the dunes and root casts and the black sand layer may represent a period of relative slow rise or still-stand at five or six feet below present sea level.

The striking problem to be explained is the truncation of the casts by the white sand cover with no discontinuity between root filling and surface cover and the apparent absence of a forest floor preserved at the contact between the two. Fire is a common agent causing the removal of old forest debris (Cooper, 1961). Fires would also remove most or all of the above ground live plant cover and would probably partially burn the roots. After removal of the plant cover in an area, the white sand could be drifted over and into the root cavities by wind action. Other possible mechanisms include killing of the forest cover by disease or rapid sand burial. The lack of surficial remains (i.e., buried trunks and branches), the apparent past cross-bedding age of the casts and the relatively thin encroached white sand layer covering the older surface would not provide either evidence or agents for these last two mechanisms.

With regard to the source and production of the organic particulate matter and the iron oxide cementing the casts, decay of plant debris in humid subtropic climates produces fine carbonized detritus and large quantities of humic acids which locally discolor runoff and ground water. These organic acids greatly increase the solubility of both Fe^{+++} and Fe^{++} in natural water (Shapiro, 1957). Alteration of these organic acids in zones of variable pH could provide a mechanism for the deposition of iron compounds with organics.

CONCLUSIONS

The described features are probably root casts of previous sand pine woods developed on and in the old dunes. In addition, the uniform development of the casts and the sharp truncation of them by the white quartz sands shows that they are part of an older sedimentary and forest regime. This older cycle appears to have been in effect about 3000 to 4000 years ago and perhaps up to within 1500 years before present. The date obtained for one case need not be representative of

the time of formation of all of the casts in the entire Apalachicola area as fires may have burned out relatively small areas at any one time.

The continuity of white sand surface sediment and case filling and the absence of evidence of surface vegetation is best explained by removal of the previous forest cover by natural fires and subsequent encroachment of the white sand. These casts may also serve as "reinforcing rod" structures in otherwise weakly consolidated sediments, hence enhancing the chances of preservation.

The formation and preservation of these features in highly permeable coastal dune sands show that even the most rigorous sedimentary environments may yet contain records of such ephemeral features as the roots of dune vegetation. Other students of organic structures may find benefit from comparisons of older "fossil roots" with these recent examples.

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